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VISUAL FATIGUE IN SONAR CONTROL ROOMS
LIGHTED BY RED, WHITE OR BLUE ILLUMINATION

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Naval Medical Research and Development Command
Research Work Unit M0100.001-1014

Released by:

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SUMMARY PAGE

PROBLEM

To determine whether visual fatigue, which can occur for some individuals working in red light at close distances, is a problem of importance for the operation of visual sonar displays.

FINDINGS

There was evidence that older, far-sighted individuals did show changes indicative of fatigue under red light while younger individuals with normal vision did not. No performance decrements were found for any group.

APPLICATIONS

The color of the illumination employed in sonar control rooms should not be a problem for almost all the men working in the room. Working in either blue or white light for an hour yields no evidence of fatigue.

ADMINISTRATIVE INFORMATION

This research was conducted under Naval Medical Research and Development Command Work Unit M0100.001-1014 - Optimum conditions for watch in sonar shacks. The manuscript was submitted on 11 Apr 1983, approved for publication on 12 May 1983 and designated as NavSubMedRschLab Report No. 1000.

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ABSTRACT

Eye movements were recorded and performance measured for subjects monitoring a simulated sonar display for an hour in red, white, or blue illumination. Subjects were four young individuals with normal vision and four older far-sighted individuals; the latter were chosen since they should be most subject to visual problems under red illumination. There was no difference in visual performance over time for either group. There were however indications of fatigue for the hyperopes in red illumination. In one hour of monitoring the displays, none of the subjects showed evidence of fatigue in blue or white light.

A series of previous investigations has been designed to investigate the popularity of blue lighting in submarine sonar control rooms.[1-4] We had postulated at least four possible reasons: a psychological effect, an enhancement of contrast sensitivity, an increase of effective illumination due to the change of spectral sensitivity of the eye at low-light levels, and discontent with red lighting due to difficulty accommodating.[1] Thus far we have shown evidence for a possible psychological effect[3] and for an increase in the general level of room illumination with low-level blue light[4] but no evidence for increased contrast enhancement[2] or for an improvement in detection ranges with blue light.[3]

This report is an empirical investigation of the final possible reason: fatigue and discomfort theoretically due to difficulty of accommodation with red lighting. One of the facts of physiological optics[5,6] is that, under normal, white-lighting conditions, wavelengths from the middle of the spectrum are focused on the retina while long wavelengths (red) are focused behind and short (blue) are focused in front of the retina. At close viewing distances, as are common in sonar control rooms, most individuals should not have difficulty adjusting their accommodation for any color of light: the range of accommodation is such that any wavelength could be brought into focus, by increasing or relaxing the accommodating muscles, a response that is generally automatic when the light is out of focus. There are however some individuals for whom this is not true. Hyperopes (far-sighted individuals) must use their accommodative mechanism to bring even distant white light into focus; they may have insufficient reserves to either accommodate for red light or to accommodate for close distances. The combination of close distances and long-wavelength, red light may be impossible for them to bring into focus without additional corrective lenses. The same statements are also true of older individuals who gradually lose their accommodative ability and cannot read in white light without correction. Long-wavelength light would, of course, be even more difficult.

Thus one of our suppositions is that there may be enough individuals who are uncomfortable in long wavelength light to account for the popularity of blue light; in comparison to red, blue light should be much easier to accommodate. (White light too should be much easier, but low-level white light is not one of the choices in sonar control rooms.)

In order to demonstrate such an effect ideally, one would want an objective measure of fatigue of accommodation, a measure of performance, and a concomitant change in both over time as the individual became fatigued. Unfortunately, there is little in the literature that suggests that this ideal can be realized.

Visual fatigue and discomfort are common subjective complaints, both in general and in sonar control rooms,[1] but fatigue of accommodation is notoriously difficult to measure objectively. Attempts to produce fatigue of accommodation experimentally and measure it go back to 1914 when Lancaster and Williams[7] tried prolonged reading, prolonged focusing at the near point and prolonged reversals of focus from near to far. Their measure of fatigue, the position of the near point, either did not change or went in the wrong direction! More recent attempts have likewise failed.[8] In one Herculean attempt, Weber[9] tested more than a dozen visual functions, during an eighteen-hour day of close work. He found no change in acuity, either near or far, no decrease in the speed of accommodation or loss of strength of the extraocular muscles, nor any change in heterophoria. Of all the functions tested, he found only a slight recession of the near point and this occurred only in some subjects.

Likewise changes in visual performance with fatigue have been very difficult to document. The literature on fatigue and performance is extensive, and a number of reviews[10-12] of hundreds of studies have come to similar conclusions. The common finding is that fatigue does not result in decrements in performance; despite long hours of work, sleep loss, and a myriad of other stresses, optimum performance can be maintained. A common explanation for the lack of decrement is that a person rarely works at his maximum level and thus has reserve energy to expend if he wishes. The conclusion of these reviews is that, while subjective fatigue may be a real warning that biological reserves are being overtaxed, it should not be used as a predictor of performance.

A typical example is the classic study by Carmichael and Dearborn[13] who required subjects to read continuously, for six hours, either books or microfilms. With few exceptions, there were no significant changes in either their measures of the eyes, behavior, or in the subject's comprehension of the material read. There was, however, subjective complaints of being tired and that the task was increasingly unpleasant as time went by. These were interpreted by the authors as due to maintaining a relatively fixed posture and muscle tensions for the six hours. Their conclusion, cited below, is typical of investigators in this field.

> "...In the use of a mechanism as well protected against deleterious effects of the prolonged work of normal reading as is the visual mechanism, the first index of fatigue seems to come in the alterations of the <u>general</u> attitudes and <u>general</u> feelings of the subject, not in a breakdown of the sensory-neuromuscular mechanism which actually performs the task."

Interestingly, a similar conclusion was reached by the National Research Council's Committee on Vision in their analysis of complaints of visual fatigue made by operators of video terminals (VDTs),[14] that is, that alleviation of demands on the musculoskeletal system would significantly reduce the stress experienced by many VDT operators.

Despite the many failures over the years in attempts to document 'visual fatigue,' the measurement of eye movements does show promise. As long ago as 1957, Deese[12] reported greater agreement among studies of oculomotor adjustment than any other aspect of visual work. Continuous reading was sometimes but not always accompanied by slower saccadic eye movements, more regressive movements, and greater variability. Hall and Cusek[15] added analysis of eye blinks to the promising studies of oculomotor adjustments and foresaw the implications of high speed measurement and data reduction to this field. It is in the latter area, the use of sophisticated computer analyses permitting the rapid and precise quantification of enormous numbers of eye movements, that the greatest advances have taken place. Using these techniques, several groups of investigators have concluded that specific changes in eye movements resulted from fatigue.

In an important series of investigations Bahill and collaborators[16-18] developed a normative data base for saccadic eye movements from a large group of subjects. In what they refer to as "main-sequence analysis", they show great regularity in the saccades of normal, unfatigued subjects: the duration and peak velocity of saccades vary with the magnitude of the saccade in a precise way. In order to determine these functional relationships between saccade parameters, it was necessary to reject data from fatigued subjects. To reduce fatigue, they had subjects make deliberate eye movements for only a few minutes at a time. A number of changes occur with fatigue: saccades become slower and more irregular; glissadic overshoots increase; long-duration corrections and double saccades (two small eye movements instead of one large one) appear; and aberrant saccades, too slow for the main-sequence analysis, become more common.[18]

Becker and Fuchs,[19] in their analysis of saccadic eye movements, come to similar conclusions. Pointing out the significant effect that fatigue has on eye movement trajectories, they state that the duration of a long, 40-degree saccade, increased during a one-hour session by 6.5%, 12.5% and 24% in three different subjects.

Another group of investigators, led by John Stern,[20] has been using computer analyses of eye movements as an indication of fatigue and alertness in a number of applications. They have recorded eye movements in skilled and unskilled helicopter pilots while flying, and found changes in both saccades and blinks as a function of time on the task.[21-22] In another study,[23] they have shown increases in saccade duration and decreases in saccade velocity for students taking valium. Analysis of blink duration likewise showed increases for the subjects on valium. Similar increases in blink duration were found in subjects operating a driving simulator while intoxicated on alcohol.[24-25]

The measurement of eye movements thus was chosen as the most promising tool in assessing the possible role of the lighting color on visual fatigue. Eye movements were recorded for subjects continually monitoring a visual display which simulates a modern sonar system, under red, white, or blue light of equal brightness.

METHOD

Displays

The subject's task was to view a simulated sonar display for frequency-by-azimuth (FRAZ) and to indicate, by pressing the appropriate number on a keyboard, where he saw the "target." Each FRAZ consisted of 15 rows of 128 rectangular marking

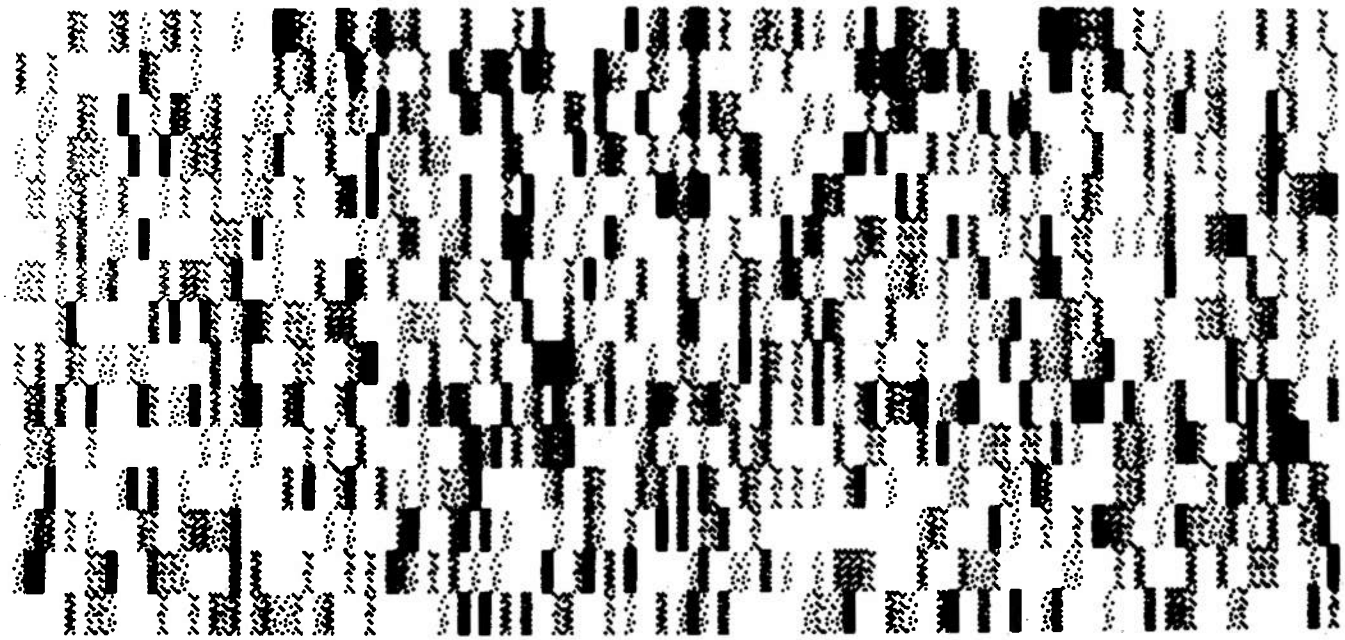

Fig. 1. An example of the FRAZ displays viewed by the subjects. In this one, the target line is #6.

spaces; each marking space could be either unmarked (dark) or marked (light) with one to five intensities of light. Targets were depicted as brighter areas (higher marking densities) in a given row. Fourteen of the rows of each FRAZ were randomly marked with the same density and intensities of light. The other row contained the "target," which had 6 to 24 extra marks randomly distributed along the row. The result was that some of the targets (6 extra marks) were almost impossible to distinguish from their background while others (24 extra marks) were quite easy to identify. A typical display is shown in Fig. 1.

Each FRAZ display was photographed, the pictures mounted in slides and projected on a screen by a carousel projector. At the observing distance of three feet, the displays subtended 18° horizontally and 10° vertically. A vertical column of 16 numbers was attached to the screen and the subject was instructed to indicate the row in which he saw the target by its number. Each FRAZ was displayed for 15 seconds, followed by a 15-sec blank screen of the same average luminance. The subject was told to enter his answer on the keyboard during the 15-sec blank period.

Forty FRAZ displays interlaced with 40 blanks were randomly inserted into one carousel. Two other carousels contained the same forty FRAZ displays in different random orders. There was one exception to the randomization procedure: at a specific point in each try the same small subset of FRAZ displays was always used. This corresponded to the time when eye movements were recorded and insured that the recordings were always done for the same displays. None of these features was known to the subjects.

Lighting

Three colors of light were employed: red, white, and blue. The red and blue were the same as used in submarine sonar control rooms, while the white was the same brightness as the red and blue.

Ambient light on the display was provided by daylight fluorescent bulbs covered by the red or blue plastic sleeves used in submarines; since these filters transmit only about two percent of the light, a filter was formed of black cloth to attenuate the light to the same level for the white condition. The amount of illumination falling on the screen was 0.3 foot-candles (fc) for all three colors; this level is toward the upper end of the range of values found in operating submarines.

In the main experiment, the display itself was also filtered to accentuate the effects of the colors. Since the projector had an incandescent light bulb, the normal-colored sleeves could not be employed. Rather, red and blue Wratten gelatin filters were chosen so that the projected light, when viewed through the appropriate filters, had the same color as the fluorescent light through the normal colored sleeves. The colors used are shown in the CIE diagram of Fig. 2. Again, for the white condition, a neutral filter was selected to attenuate the light so that the luminance of the display was the same as that of the red and blue light. The luminance of the FRAZ displays

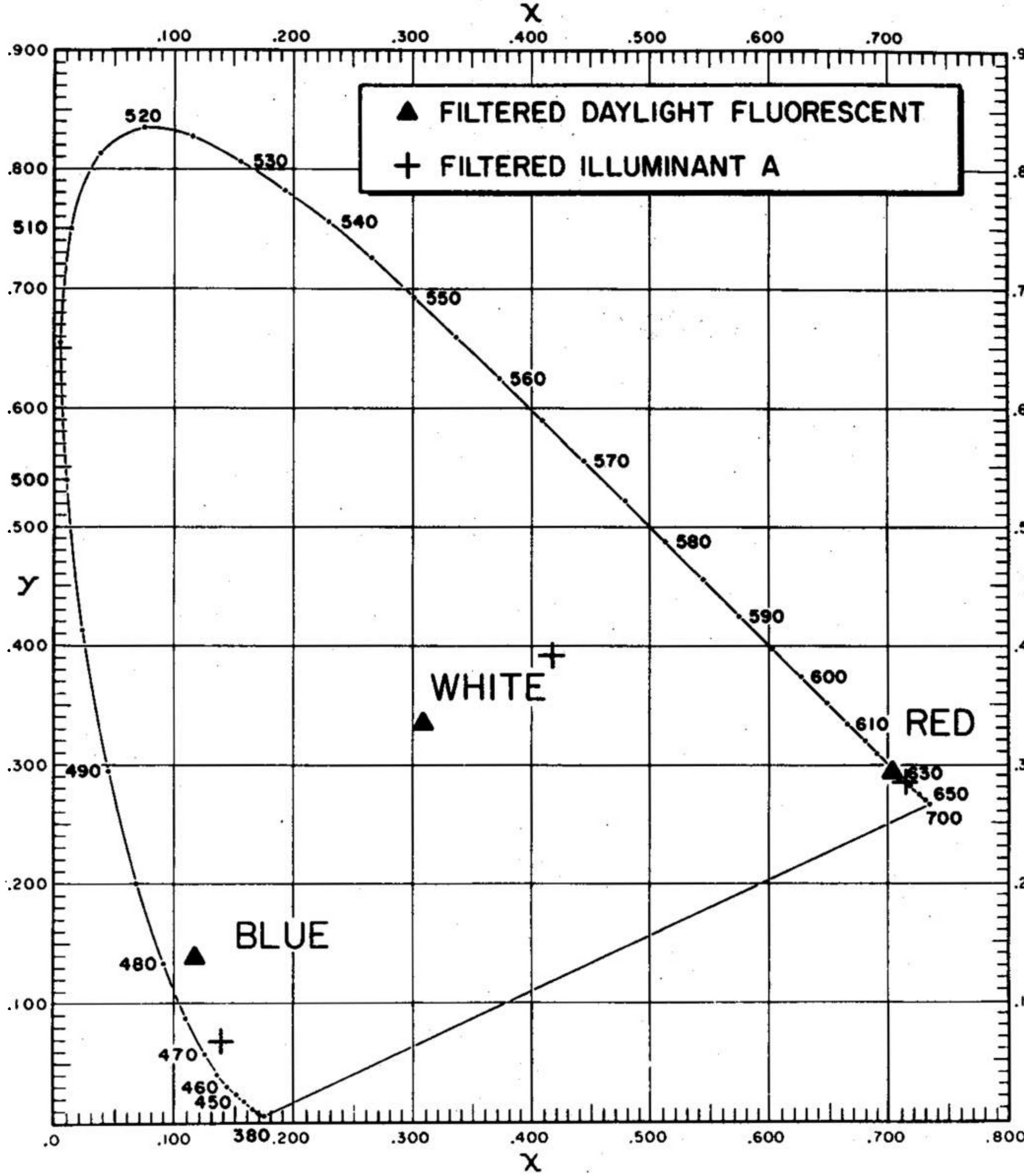

Fig. 2. The color of the lights used in the experiment, plotted on the CIE chromaticity diagram ▲ depicts the colors of the ambient illumination (obtained by filtering fluorescent light bulbs) and + the projected colors (obtained by filtering the carousel projector).

was 1.0 foot-Lambert when attenuated by the red, white, and blue filters.

Eye Movements

Electro-oculograms were recorded in a routine manner using five Beckman silver-silver chloride electrodes. The potential difference between electrodes mounted at the outer canthus of the right and left eyes represented the horizontal eye movement record and that between electrodes mounted just above and below the left eye the vertical movement. The reference electrode was placed in the middle of the forehead. The potential differences were amplified by Grass 7P122 amplifiers, monitored on a two-channel oscilloscope, and recorded on a FM tape recorder.

Eye movements were analyzed by a computer using a specially developed program* which provides measures of both blinks and saccades. The analog signal was digitized in 10-msec intervals and any number of 10-sec intervals could be selected for analysis. Information was given on the number, size and duration of blinks, and on the number, magnitude, duration, and peak velocity of saccades.

Subjects

Data were collected on eight subjects from the laboratory staff, who comprised two distinct groups. Four of the individuals were young (between 20 and 28) and had normal, good vision; these form the emmetropic group. The other four subjects were very far-sighted, with refractive error greater than four diopters. They also were older (between 38 and 57 years of age); these form the hyperopic group. Thus accommodation should be a minor problem for the younger emmetropes, while it should for two reasons be difficult for the older hyperopes.

Procedure

Subjects read the instructions, which are given in Appendix A, signed the consent form, and were shown a series of 20 practice slides to ensure that they understood the instructions and procedure. They were informed of the correct answers while viewing the practice slides.

Electrodes were then attached, low resistances verified by measurement, and the subject seated three feet from the screen. Voltage differentials were amplified and calibrated by having the subject view a pattern of vertical and horizontal dots which were ten degrees apart at this viewing distance. The signal was amplified, while the subject made deliberate fixations from left to right and back (and up and down, etc.) until it measured 500 mvolts on the oscilloscope. Following the calibration, the dots were removed and the carousel projector started.

Subjects viewed the FRAZ displays for an hour, responding with the location of the target for each slide. Every twenty minutes carousels were quietly interchanged and the procedure continued without interruption. Eye movements were recorded for four minutes beginning at eight minutes

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* We are grateful to Dr. John A. Stern for allowing us to use the program developed at Washington University and to Dr. Larry Walrath for the program changes required by our computer installation and for the necessary instructions on its use.

following the start of each try; thus the average time of recording corresponded to ten, thirty, and fifty minutes of monitoring the FRAZ displays, It was at these temporal intervals that the FRAZ displays were the same in each tray, although in different order, so that the displays themselves did not influence the pattern of eye movements.

Each subject was tested in each color of illumination, on different days, at least two days apart; the order of presentation of the colored illumination was counterbalanced across subjects.

Preliminary Experiment

Prior to the main experiment, the viewing procedures and the techniques for recording eye movements were tried on a group of six young men with normal vision. Both eye blinks and performance in terms of the number correct on the FRAZ displays were measured. The FRAZ displays were monitored for a two-hour period by incorporating extra carousels of 140 slides into the procedure. The ambient illumination was the same red, white or blue described above, but the FRAZ displays were projected by incandescent white light in the carousel projector. All other details were the same as in the main experiment.

The percentages of correct responses on the FRAZ displays are shown in Fig. 3 as a function of the average time at which the carousels were viewed. For example, it took twenty minutes to complete the first tray of slides; the average number of correct responses on this tray is plotted at ten minutes. The mean and standard deviations for all three colors, at the left, show that there are no differences in performance as a function of time. Similarly, the mean data for the red, white and blue light, plotted separately on the right, show no effects due to the color of the ambient illumination.

Fig. 4 shows a similar analysis of the mean blink duration. For this criterion, there is an increase in duration as a function of time; the longer blinks are found even after one hour of viewing the displays and continue to increase throughout the two-hour period. Again, there were no effects of the colored illumination.

Decisions as to the experimental protocol for the main experiment were based upon these preliminary data. Since there was no gain in information obtained from the second hour of viewing, the experimental sessions were cut to one hour to make it easier to obtain volunteers. The lack of effects due to the color of the illumination prompted two changes to enhance their effects. First, the colored filters were placed on the projector, so that the subjects viewed red, white, or blue FRAZ displays in comparable red, white or blue ambient illumination. Also subjects who presumably should have difficulty accommodating in red light were selected for inclusion in the study.

RESULTS

Data analysis includes a performance measure, percentage of correct detections on the FRAZ displays, and a variety of indices from the electrooculograms including measures of both blinks and saccades. These are presented in turn below. In each

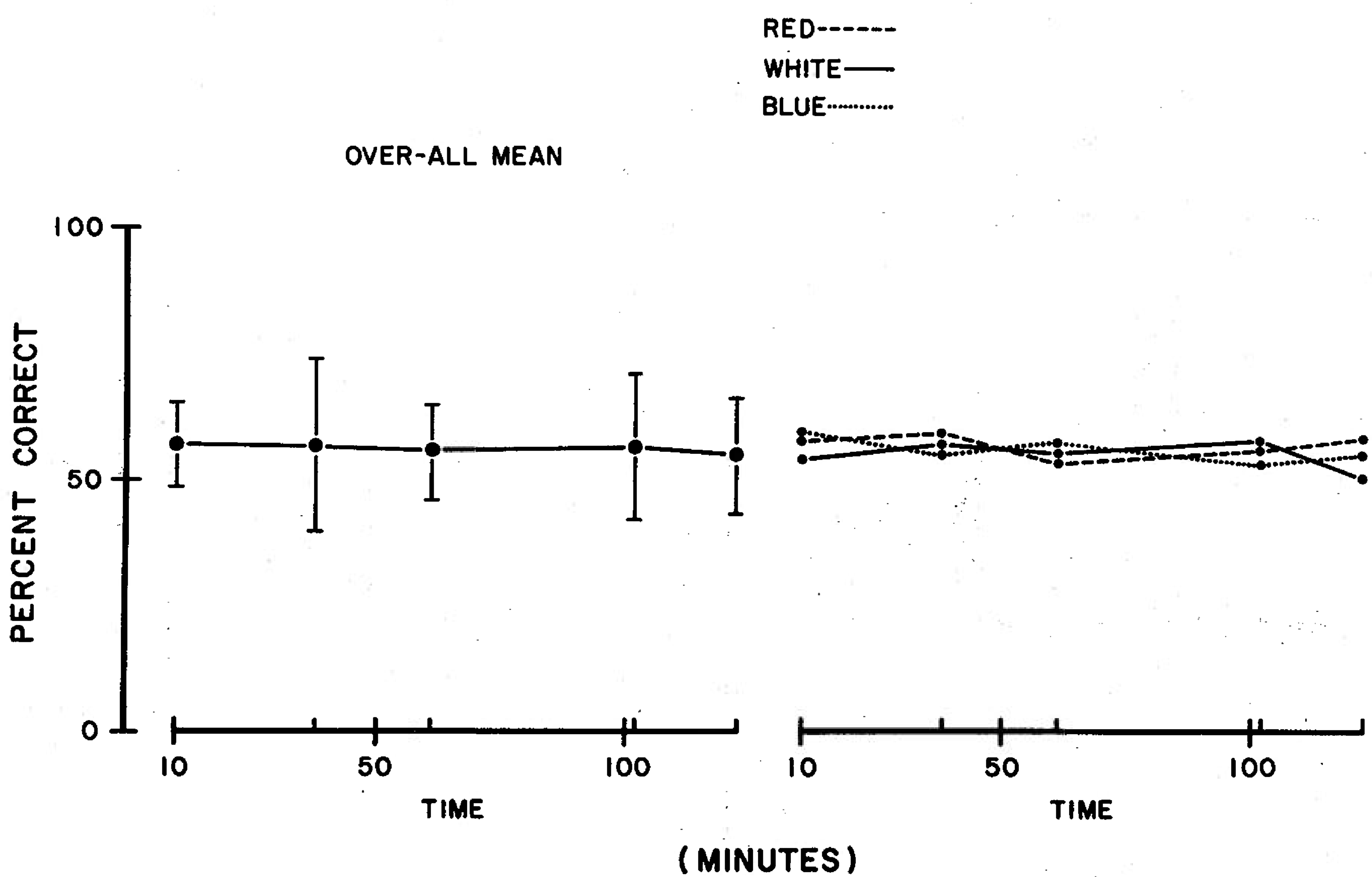

Fig. 3. The mean percentage of correct responses on the FRAZ displays as a function of time. Subjects are six young men with normal vision.

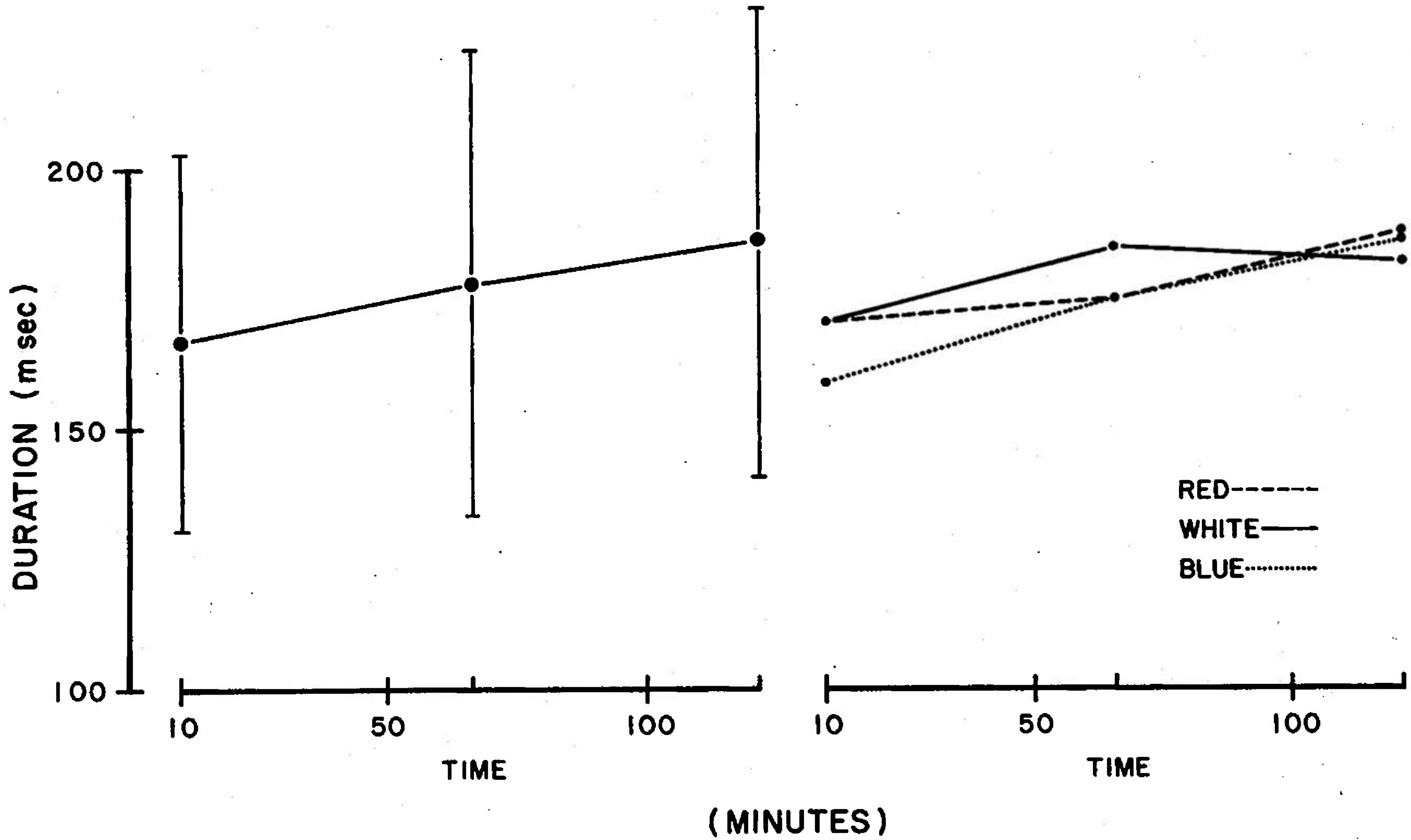

Fig. 4. The mean blink durations for six young men as a function of time.

case, the data are presented as a function of time during the testing session, with the color of the illumination as the parameter.

Performance

The mean percentage of targets identified correctly is shown in Fig. 5. The overall mean, for all subjects and conditions, is shown at the left. As in the preliminary experiment, there is no deterioration of performance over time; indeed, there is a slight increase in the mean percent correct during the final session. The average performances of the emmetropes and the hyperopes in the different colors generally show the same trends. Both groups did slightly better in white than in red or blue light; this difference is significant for the total group ($F(2,14) = 4.7$ $p < .05$). Also both groups generally function as well or better at the end as the beginning; the major exception is the hyperopes in red illumination whose percentage of correct responses decreased slightly in the third session. While the differences obviously are very small, the decreases were found for three hyperopes while the fourth showed no difference at all over time.

Analysis of Blinks

There were no systematic differences in blink rate for the various colors for the two groups of subjects. There were, however, very large individual differences with some subjects showing rates of 3-4 per minute while others blinked 20 times per minute. The mean for all subjects and all conditions was 9.4 blinks per minute. Both the average value and the size of the individual differences are quite comparable to those found in the literature for normal subjects under normal conditions.[15]

The average blink duration for all subjects and all colors over time is shown in the left of Fig. 6. There is an increase in the duration during the 50-minute data collection. Analysis by groups of subjects, in the remainder of the figure, shows that this increase is due primarily to the hyperopes in red illumination; again, three out of the four hyperopic subjects showed a sizeable increase in duration.

Analysis of Saccades

There were a number of analyses of saccades available from the computer program. First, a simple count of the number of saccades did not show systematic differences. The mean number for both the emmetropes and the hyperopes was about 51 saccades per minute. There were, however, large individual differences, varying from about 20 to 100 per minute, in both groups.

Saccade duration - Mean values of length of time taken to complete saccades are given in Fig. 7. The overall mean shows a slight increase over the fifty-minute period. Separate averages for the emmetropes and hyperopes show systematic differences over time for the red illumination only. Durations for the white illumination remained relatively constant over time while those for the blue were somewhat erratic.

Saccade magnitude - Frequency distributions of saccade magnitude were skewed, with the majority of

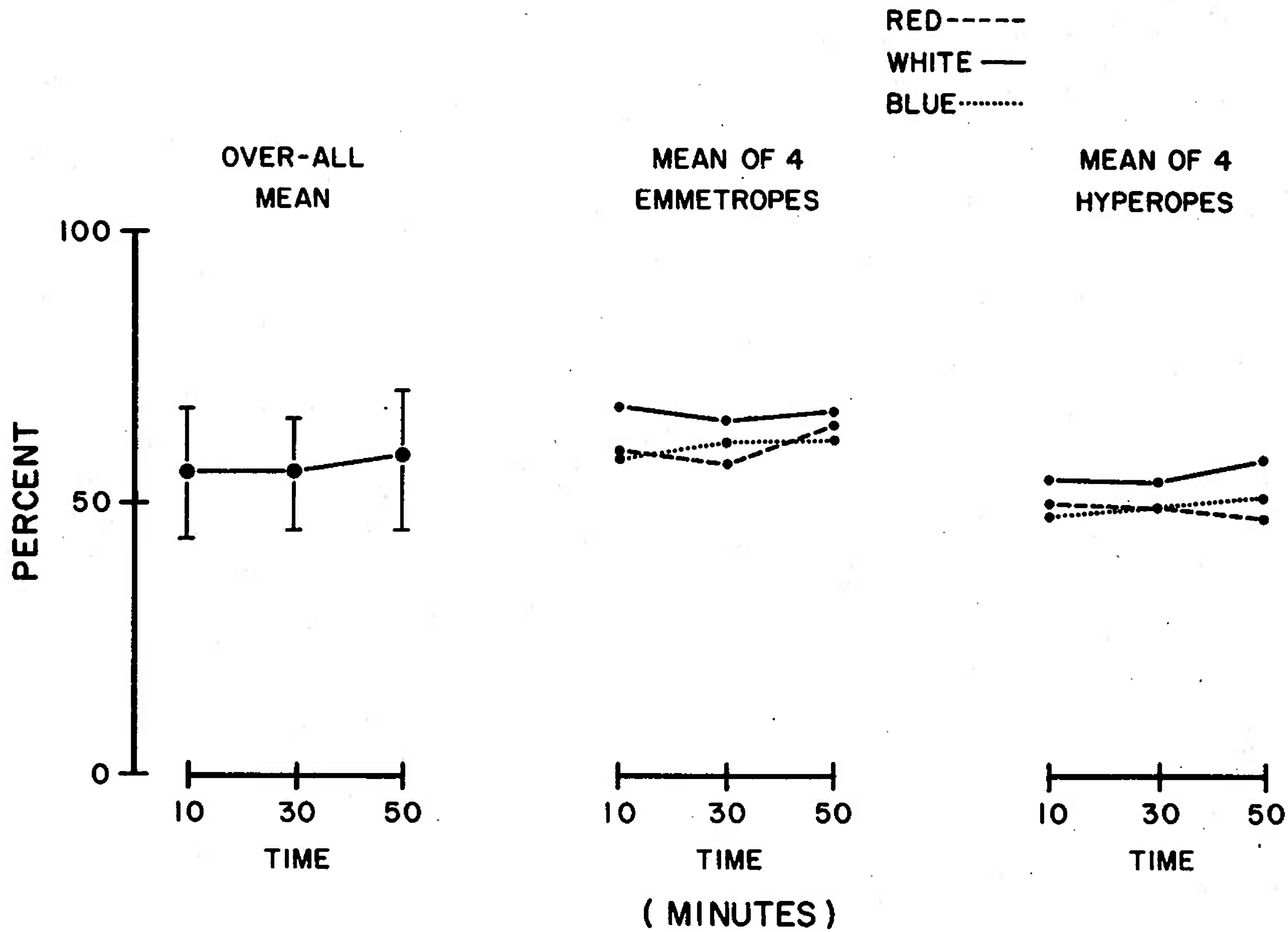

Fig. 5. The average percentage of correct response on the FRAZ displays as a function time. Left: means and standard deviations for all subjects and all conditions. Right: means for emmetropes and hyperopes as a function of the color of the display.

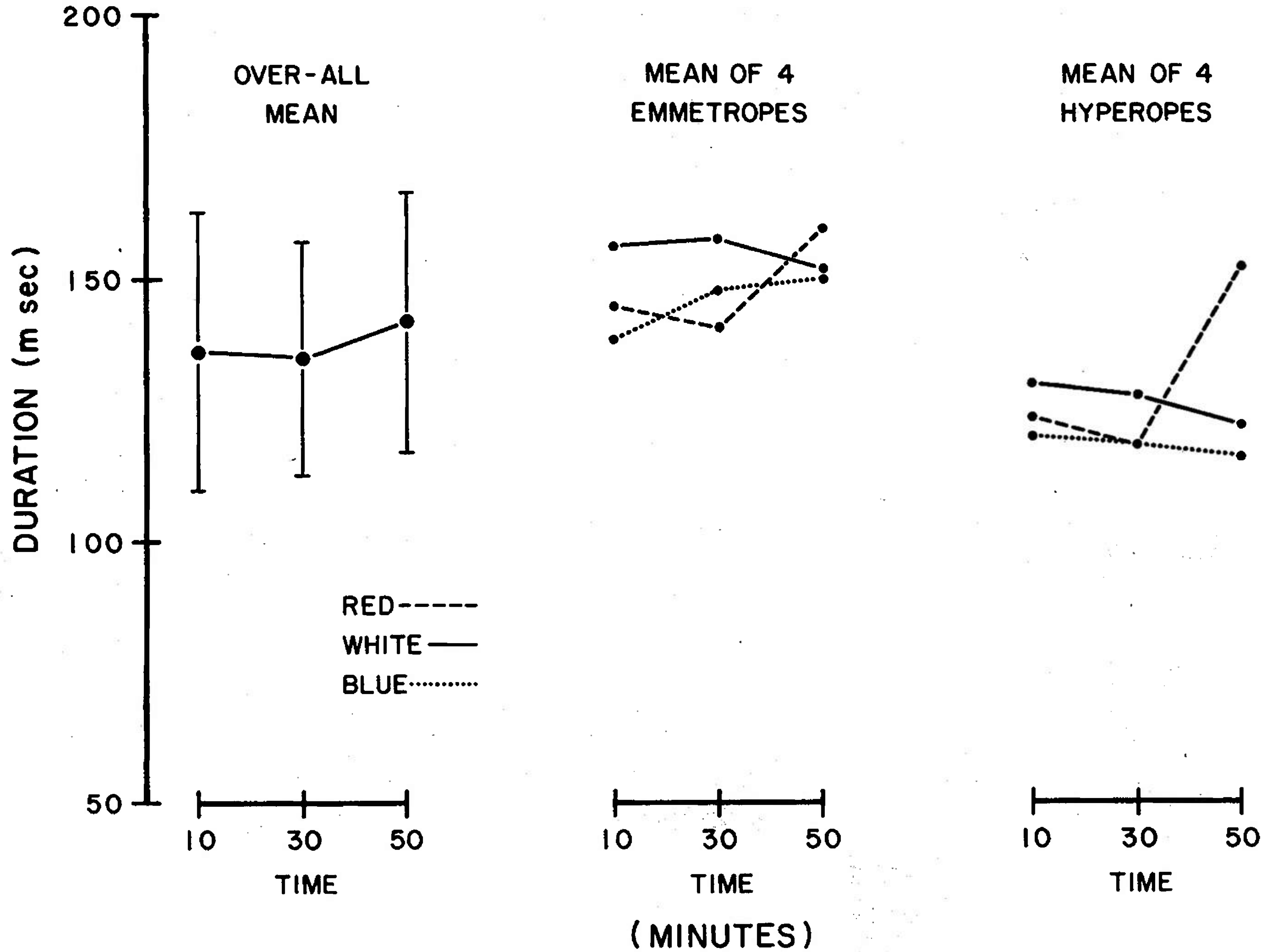

Fig. 6. The average blink durations as a function of time. Same format as Fig. 5.

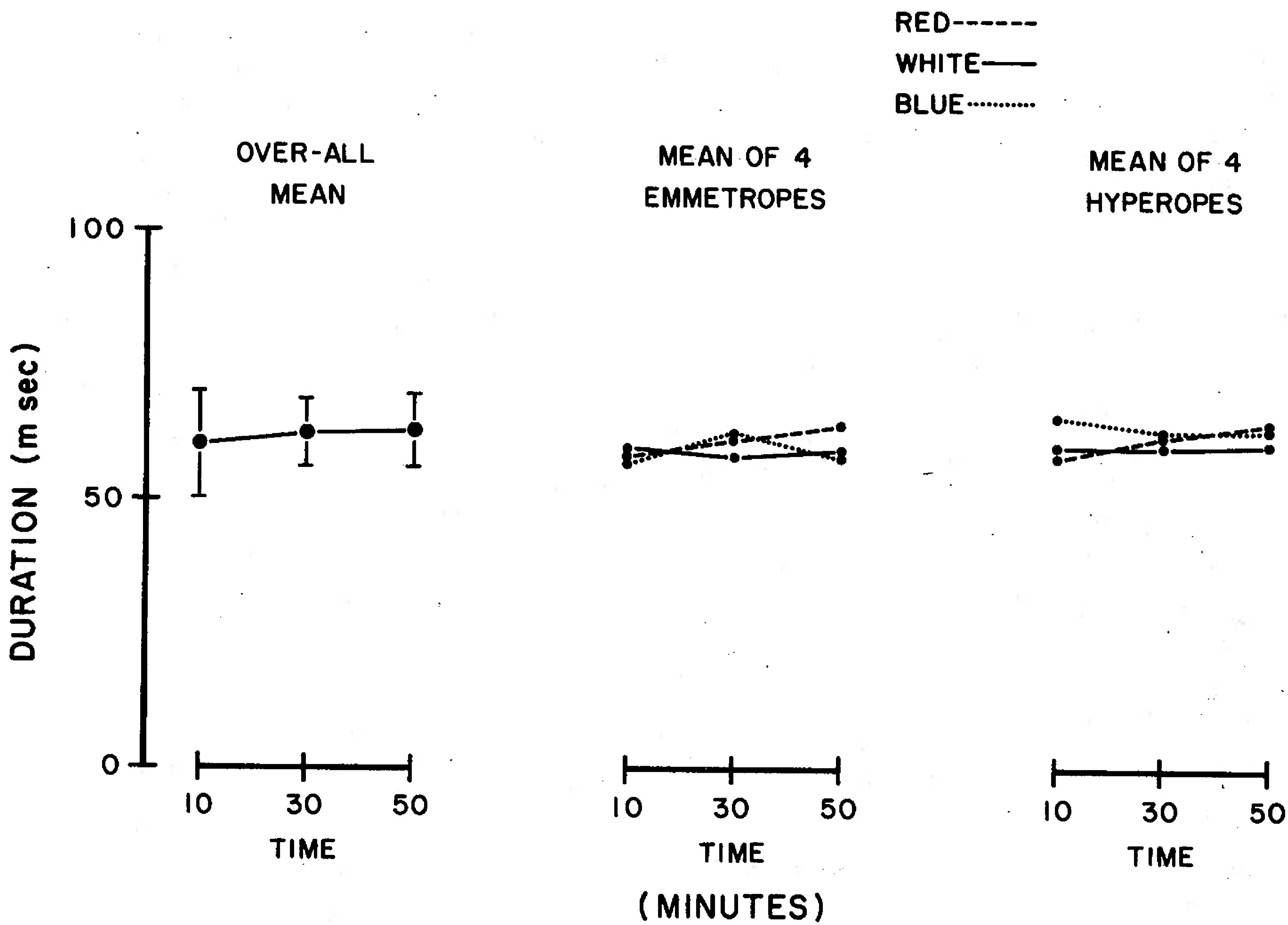

Fig. 7. The average saccade duration as a function of time. Same format as Fig. 5.

the saccades registering two to eight degrees in size. A histogram of a typical distribution is shown in Fig. 8. Since the few very large saccades would contribute disproportionately to the mean, median saccade magnitudes were calculated for each session. These medians were averaged over subjects and are shown in Fig. 9. Since there could be small differences in magnitude from one session to another, due to electrode locations and amplification, the results were analyzed in terms of magnitude relative to the first recording session of the day. Saccade magnitudes increased slightly over time; this was particularly true for the hyperopes in red illumination.

Saccade velocity - The increase in saccade magnitude over time, described above, complicates the analysis of saccade velocity since it is well known that larger saccades are faster than smaller ones. The relationship is that of a power function which appears as a straight line between the log of the magnitude and the log of the peak velocity. An example of the relationship for one subject for one minute of data is shown in Fig. 10. Each point represents one saccade and the line is the best fit derived from the function

$$y = ax^b$$

where y = saccade velocity and x = saccade magnitude. Thus we would expect the peak velocity to increase over time if the magnitude increases, all other things being equal.

Fatigue, however, should result in decreases in saccade velocity over time, particularly for the larger saccades. In order to determine whether velocities are decreasing when magnitudes are increasing, power functions were fit to the individual data for the first and last sessions and the constant and exponent calculated. These values are given in Table I. All of the saccades in a given recording session of 2.5 minutes were used in the determinations; thus there were generally 100 or more data points upon which each function was based. For the emmetropes' data, the exponents usually increased slightly during the third session. For the hyperopes' data, there is more variability with some increases and some decreases in exponents. However, for the red illumination, the exponents for all four hyperopes decreased during the third session indicating that their saccade velocity for larger saccades was decreasing.

The constants and exponents were averaged for the two groups and the resulting best fit functions plotted in Figs. 11 and 12. The data for the emmetropes, Fig. 11, are completely regular and there is no indication of fatigue for any of the colors; in fact the last session was always slightly better than the first. For the hyperopes (Fig. 12), however, there is more variability and the third session for red was flatter than the first. This is the only indication of fatigue in the analysis of saccade velocity.

DISCUSSION

Performance on the simulated sonar display did not deteriorate in any color of illumination, either in the preliminary two-hour study or in the main one-hour study. This occurred despite the fact that the task was somewhat boring and unpleasant for some subjects as evidenced by complaints and difficulty getting

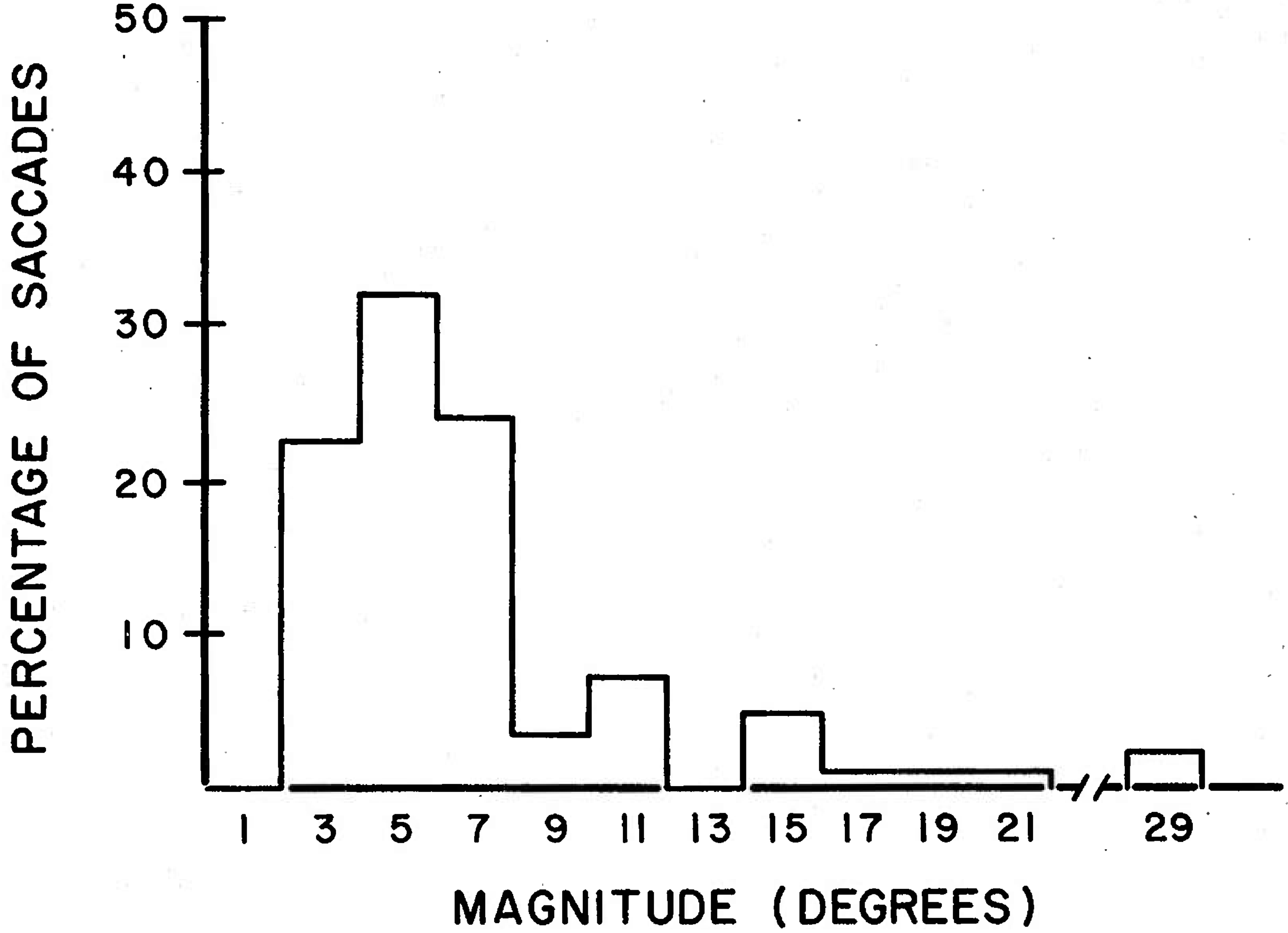

Fig. 8. A typical distribution of the magnitudes of saccades for one recording session for one subject. Eighty-four saccades are depicted here; the median size is 5.7 degrees.

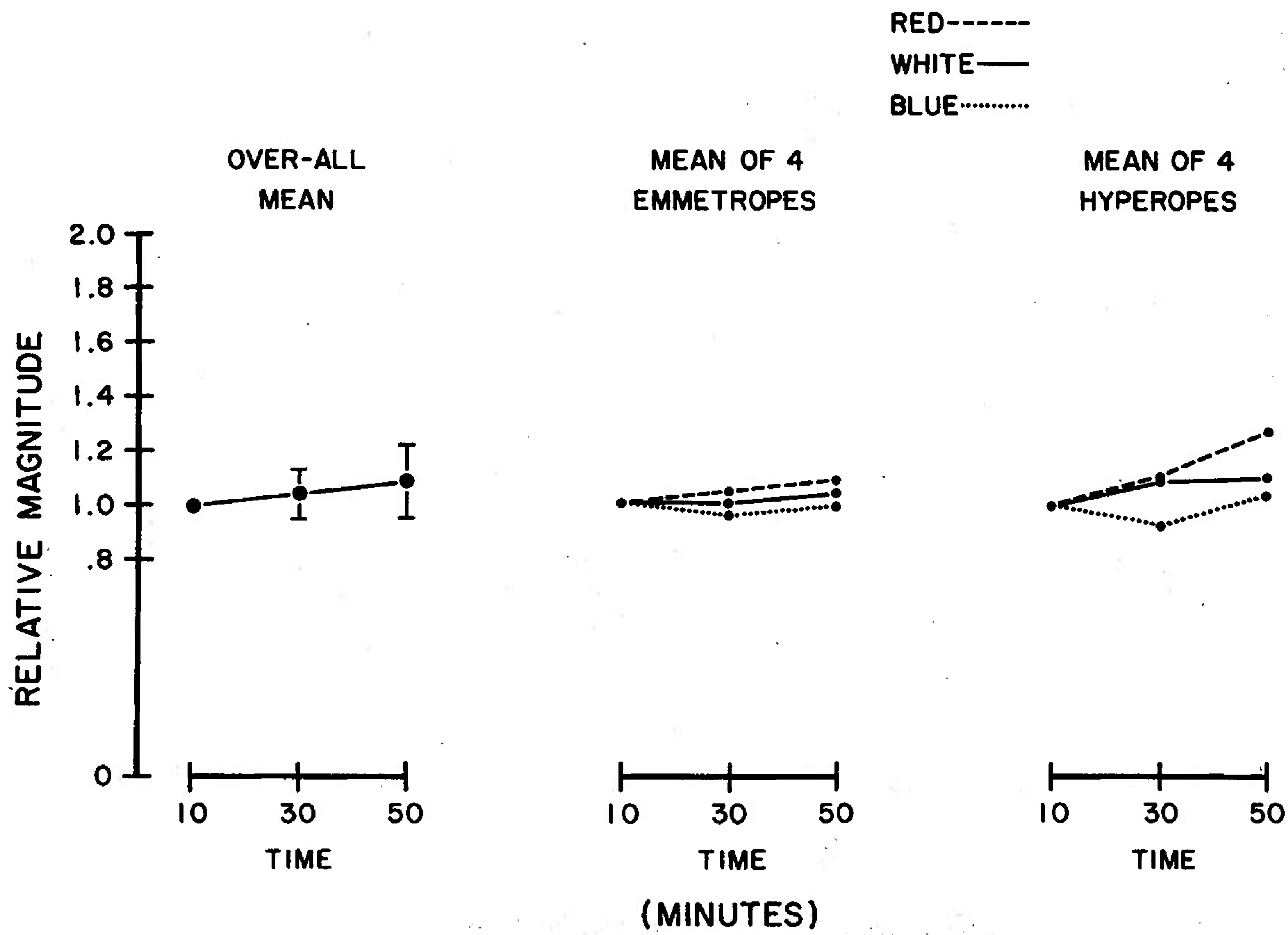

Fig. 9. Relative saccade magnitude as a function of time. Same format at Fig. 5.

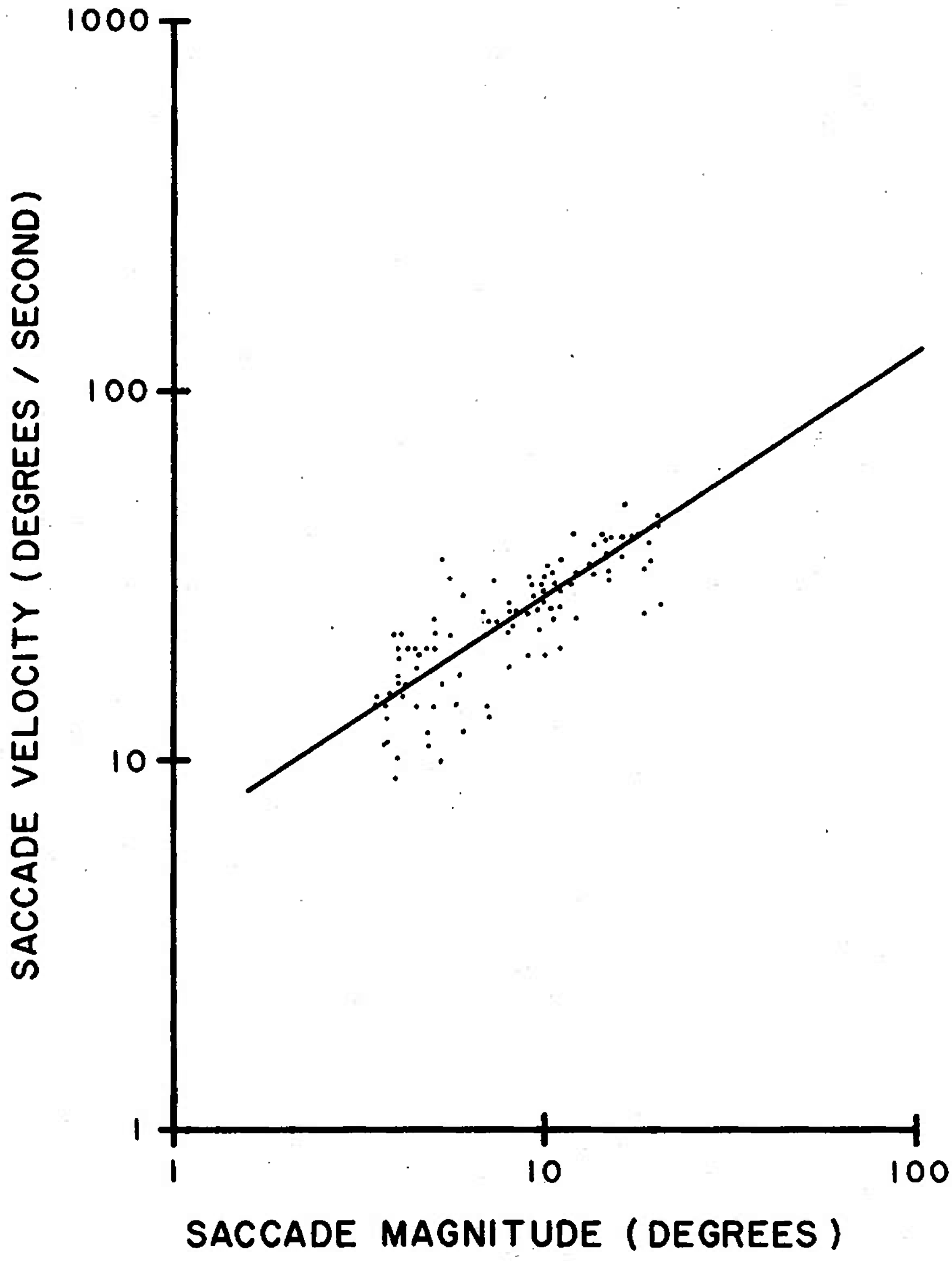

Fig. 10. The velocities of individual saccades as a function of their magnitudes for one minute of data for one subject.

Table I. The slope of the function relating saccade velocity to saccade magnitude in the first and last sessions

Subjects	Red 1st Session	Red 3rd Session	White 1st Session	White 3rd Session	Blue 1st Session	Blue 3rd Session
Emmetropes						
1	.38	.40	.43	.48	.54	.48
2	.47	.56	.65	.62	.50	.65
3	.49	.42	.67	.73	.54	.56
4	.54	.62	.60	.66	.63	.62
Hyperopes						
1	.66	.58	.50	.45	.58	.59
2	.66	.53	.55	.66	.38	.60
3	.59	.57	.57	.61	.47	.48
4	.38	.25	.47	.26	.55	.43

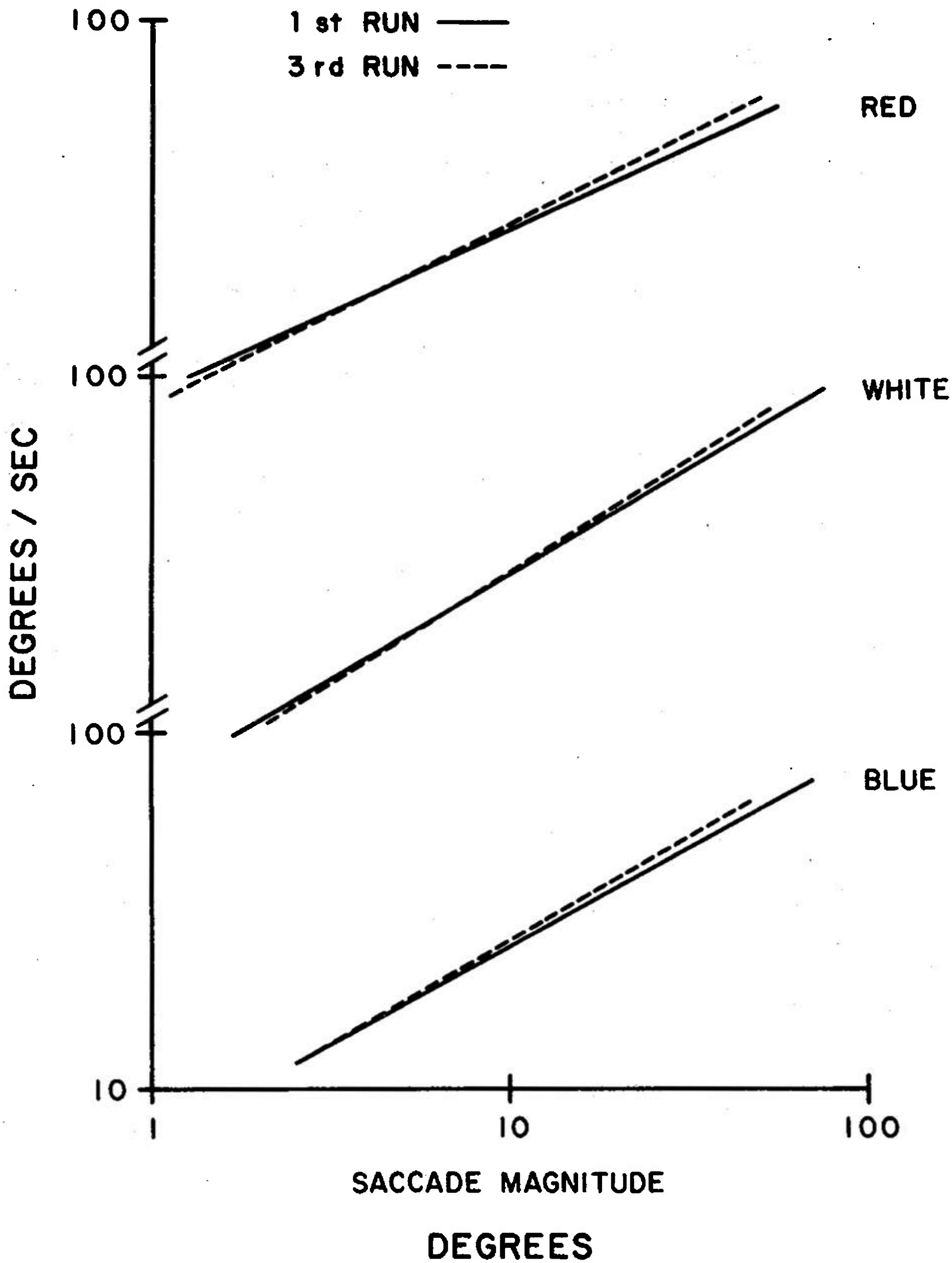

Fig. 11. The best-fit relationship between saccade magnitude and velocity for different colored lights. Mean responses for four emmetropes. The ordinates for blue are correct; the data for white and red are displaced upward by one and two log units, respectively, for ease of viewing.

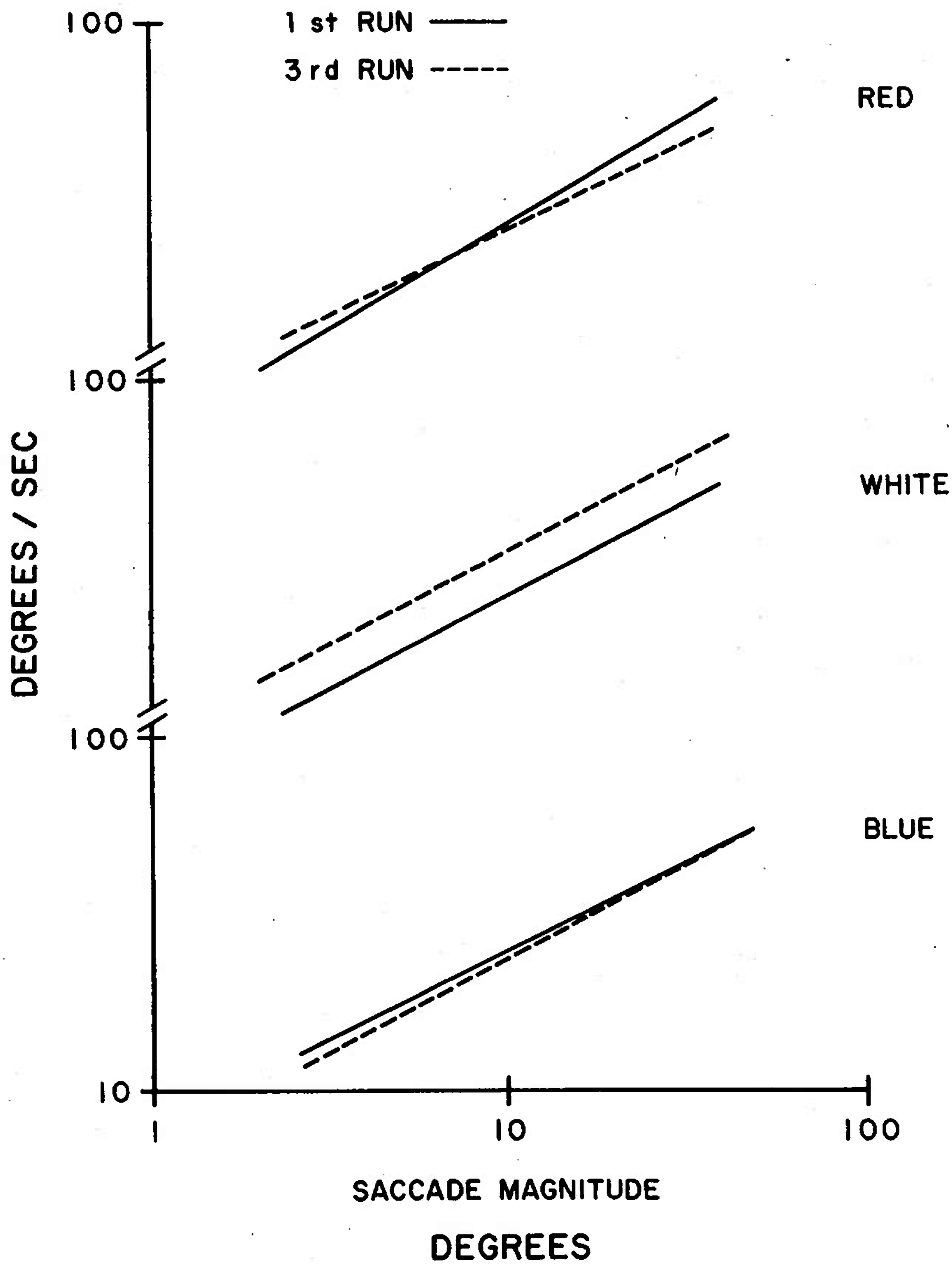

Fig. 12. The best-fit relationship between saccade magnitude and velocity for different colored lights. Mean responses for four hyperopes. The ordinates for blue are correct; the data for white and red are displaced upward by one and two log units, respectively, for ease of viewing.

subjects to return. This result is in complete accord with the literature[10-12] which shows that visual performance is usually very resistant to fatigue. We must therefore look to the results from the eye movements for any evidence of fatigue.

A number of changes in eye movements with fatigue can be predicted from the literature of eye movement recording. These are increases in the duration of blinks,[21-25] increases in the duration of saccades,[18,19] more irregularity in saccades, and increasing deviations from the main-sequence analysis.[16-18] Since the larger saccades are the most susceptible to fatigue,[18] the deviations from the main-sequence analysis should appear as decreases in the peak velocity for the larger and not for the smaller saccades; this in turn should result in a decrease in the slope of the function relating the two measures.

Comparison of our eye movement results with these predictions does show evidence of fatigue. For blink durations, increases were shown in the preliminary study for all colors during the two-hour sessions and in the main study for the hyperopic subjects working under red illumination. In the analysis of saccade velocity, decreases in the slope of the function relating it to saccade magnitude* was found for the hyperopic subjects in red illumination.

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*The reason for the slight increase in magnitude over time is unknown; it may reflect simply more efficient movement to find the number on the side as one gets used to the task.

Several points must be considered in the interpretation of these results. First, the differences are small and rarely statistically significant. Statistical analysis for only four subjects, in the case of the hyperopes versus the emmetropes, is of course not reliable, and most of the differences were found only for the hyperopes. On the other hand, it was predicted that hyperopes would be bothered by red illumination and this prediction was borne out in all cases; this then is significant in the non-statistical sense.

Assuming then that we have some evidence for a fatiguing effect of red on hyperopes, comparison of our hyperopic group with the submarine, sonar population becomes important. Our group was both older (over 38) and hyperopic (over +4 diopters) and the incidence of both of these attributes among submarine sonar technicians is small. We recently tested large groups of sonar technicians as part of another investigation; in over 200 men, there was none over 40 years of age and only two were 39.[26,27] Similarly, in the longitudinal health study of over 750 submariners, we found only three men with hyperopia of greater than four diopters.[28] Thus the chances of there being a sonar technician on a submarine comparable to our hyperopes is exceedingly slim. (It should be pointed out however that, should such an individual exist, he would likely be an experienced sonar technician in a position of authority, thus contributing to the psychological effect alluded to earlier.[3])

The unlikelihood of sonar technicians being old or far-sighted enough to be bothered by red lighting together with the small size of the effects suggest that there is no reason here to be concerned about red lighting. On the other hand, if there is no need for its use, then blue or white would be better choices. Operational considerations other than visual comfort may dictate a specific color of illumination, such as red to improve dark adaptation or white to allow color coding. The choice between blue and white, from the data in this investigation of fatigue, is immaterial: there were no differences in eye movements between the two colors. The slight superiority for white in performance could however be important if replicated.

An additional conclusion can be drawn from these data: continuous monitoring of sonar displays for an hour can be maintained in either white or blue light without degradation of performance or evidence of visual fatigue. This result is important for the length of rotations on sonar watches. In our survey[1] we found that some crews rotated every half-hour; this precaution is unnecessary in the proper illumination.

SUMMARY

No differences in performance over time were found for either the hyperopes or the emmetropes in any color of illumination. The evidence from the eye movement records suggests some fatigue for the older group of hyperopic subjects when working in red illumination. There was no evidence of fatigue in either blue or white illumination in any of these subjects.

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APPENDIX A

INSTRUCTIONS

On the screen you will see a series of slides which simulate one type of a sonar display. Each slide has a pattern consisting of a number of rows with random marks which vary in brightness; this represents random noise in the sonar. One row has extra marks; this represents a sonar contact or target. Your task is to find which row contains the target. Some of the targets are easy to see, some very difficult.

First look at the display and decide which row has the target; then look at the left and select the number which best lines up with the row you have selected. You may use half-rows; that is, if you think the target row lies between the numbers 6 and 7, call it 6-1/2. Hit the keys of the calculator to indicate your response.

This will continue for a long time - a couple hours. Try to stay awake, do the best you can and if you do not know where the target is, take your best guess. From time to time someone will come in and change the slide tray. We will have a short practice series before we begin so you get the idea.

Every other slide is a blank. When a pattern slide come up try to continue looking at it for the entire time it is on the screen. Then during the blank period, put your answer on the calculator.

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Eye movements were recorded and performance measured for subjects monitoring a simulated sonar display for an hour in red, white, or blue illumination. Subjects were four young individuals with normal vision and four older far-sighted individuals; the latter were chosen since they should be most subject to visual problems under red illumination. There was no difference in visual performance over time for either group. There were, however indications of fatigue for the hyperopes in red illumination. In one hour

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of monitoring the displays, none of the subjects showed evidence of fatigue in blue or white light.